

Application of surfacing using consumable electrode with an additional filler wire to ensure the required operational properties of pipeline valves

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Abstract. A promising way to ensure the required operational properties of pipeline valves with a significant increase in productivity and quality of surfacing during its manufacture is the introduction of anti-corrosion surfacing technologies using a consumable electrode with the supply of an additional filler wire. A solution to the optimization problem of the proposed surfacing technology is complicated by a large number of its parameters, therefore the task was solved in stages. At the first stage, the parameters of the arc interaction between the electrode and filler wire was determined, and at the second – the specific features of the formation of the surfacing bath with such interaction. A virtual study of the process of surfacing with Inconel 625 wires in argon on steel 09G2S was carried out. The influence of the thermal effect of the deposition mode parameters on the main metal is determined. It has been established that, due to the fact that the heat flux in the main metal is created mainly by the droplet stream of the deposited metal from the main arc at high currents, the diameter of the electrode wire guaranteeing its burning should be larger than the filler wire.

1. Introduction

Often, in the manufacture of parts and assemblies of pipeline valves, cheaper unalloyed steels are used, and the required anticorrosive properties of the sealing surfaces are provided by surfacing with alloys and high alloys. Therefore, surfacing is currently a priority in ensuring the required operational properties of sealing and contact surfaces of pipeline valves. Depending on the operating conditions of the pipeline valves, iron-based surfacing materials with the addition of chromium, nickel, cobalt, niobium, for example Inconel 625 are used.

Improvement of productivity and the quality of work performed can be provided by implemented automation of surfacing processes. Automatic surfacing with a non-consumable electrode and filler wire ensure process continuity with effective regulation of the substrate metal fractions in the deposited layer. However, it requires constant monitoring of the condition of the non-consumable electrode, since by wearing-out of its working surface, the melting ability of the arc decreases sharply. Conversely, with more efficient automatic surfacing with a consumable electrode, even with the addition of a filler wire, it is more difficult to achieve a minimum penetration of the base metal. Given



the capabilities of automation, such promising technique could be a high-tech process of robotic surfacing with a consumable electrode with the supply of an additional filler wire to the front of the weld pool to shield the thermal effect of the arc [1, 2]. And with a science-based selection of materials for the electrode and filler wire and surfacing modes, it is possible to obtain the required chemical composition of the joints [3].

2. Materials and Methods

A solution to the optimization problem of the proposed surfacing technology is complicated by a large number of its parameters (speed of surfacing and wire feed, their diameters, voltage and arc current, amplitude, period and shape of vibrations, initial temperature of base material) and many quality indicators (dimensions and shape of the deposited layer, penetration depth and the thickness of the deposition, the chemical composition of the deposited metal, the properties of the deposited layer). Therefore, such a multi-level task should be solved in stages. At the first stage, the parameters of the arc interaction between the electrode and filler wire should be determined, and at the second – the specific features of the formation of the surfacing bath with such interaction.

At present, among modern methods of studying welding and surfacing processes that reduce the time and number of experiments, physical and mathematical modeling is distinguished. In this regard, we will first consider modeling the arc interaction during surfacing, and then we will perform modeling of the features of the formation of the molten pool taking into account the arc interaction of the electrode and filler wires.

First of all, we outline the modeling space for arc interaction during surfacing with a consumable electrode with an additional filler wire. A rational way of feeding the electrode wire (see Figure 1) is to feed it perpendicular to the plane of the base material, and the filler wire at an angle α so that its axis intersects the axis of the electrode at a given distance L_2 from the contact tip, and the second contact tip is located at a distance L_2 from the point of intersections. In this case, the first arc a burns between the electrode wire 1 and the base material 3, and the second arc b – between the consumable electrode and the filler wire 2. During modeling, the distance x_e from the point of intersection of the axes of the wires to the base material must be taken into account. Moreover, in our opinion, to exclude cases of welding ('freezing') of the non-melted filler wire in the solidified metal of the weld pool tail, it is advisable to feed the wire into the welding pool head.

In addition to the location of the arcs, the feed rates and the diameters of the electrode v_e , d_e and filler wires v_f , d_f must also be taken into account in the the modeling space. For the main arc (a), the open circuit voltage U_e , is set, and for the additional arc (b) – current I_f . It should be noted that the current I_e of the main arc is self-alignment due to the effect of self-regulation of its length l_e , in return, the voltage of the additional arc is determined by its length l_f .

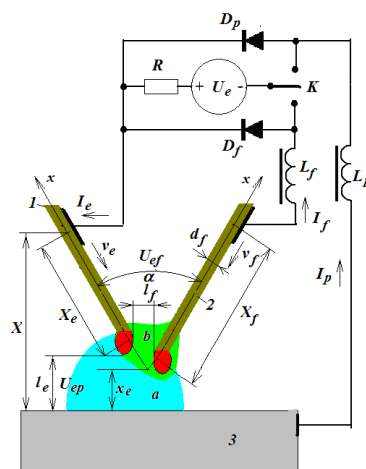


Figure 1. The modeling space for arc interaction during surfacing with a consumable electrode with an additional filler wire.

3. Results

During arc interaction, the control actions are the feed speeds of the electrode and filler wires, the open circuit voltage of the power source and the relative switch closure rate, which controls the voltage ratio of the main and additional arcs. These control actions determine the currents of the arcs, their lengths and the distribution of the process power. Additional parameters that determine the regulation results are the diameters of the wires, their stick outs, the angle between them.

Figure 2 shows the effect of the feed speed of an electrode wire with a diameter of 1.6 mm from Inconel 625 alloy on the current I_e of the main arc, the power P_k released in the cathode spot, the power P_e of the heat flow of the droplets of the electrode metal, the temperature T_e of the electrode stick out, and the length l_e of the main arc.

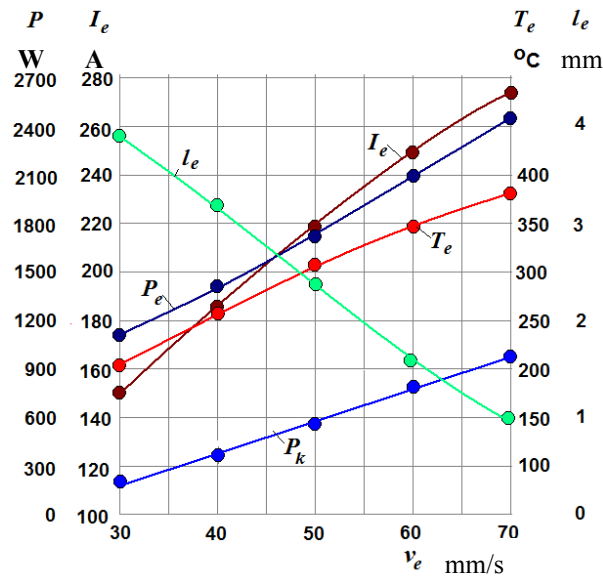


Figure 2. Dependence of the main arc parameters on the feed rate v_e of an electrode with a diameter of $d_e = 1.6$ mm from Inconel 625 alloy at a stick out of $l_e = 10$ mm, a supply voltage of $U_e = 32$ V, pulse ratio $t_e/\tau = 0.5$, and an additional arc current of $I_f = 108$ A.

During virtual research, it was found that an increase in the feeding speed v_e of the electrode wire at a fixed current I_f of the additional arc, the current I_e , flowing through the electrode increases almost in proportion to the speed. The deviation from proportionality is explained by a noticeable increase in the temperature T_e of the electrode stick out. For the same reason, the power P_e , that is heating the electrode increases at a faster rate than the arc current I_e . The power P_k , released in the cathode spot on the surface of the base material is almost proportional to the feed rate, but much less than the thermal power P_e of droplet stream. The length l_e of the main arc decreases linearly as the electrode feed rate increases. At the increase in the feeding speed v_e of the electrode wire at a fixed current I_f of the additional arc, the current I_e , flowing through the electrode increases almost in proportion to the speed.

The parameters of the additional arc are also important. Figure 3 shows the effect of the feed speed v_f of a filler wire with a diameter of 1.2 mm from Inconel 625 alloy on the current I_f of the additional arc, the power P_k , released in the cathode spot, the power P_f of the heat flow of the droplets of the filler wire metal, the temperature T_a of the heated electrode stick out, and the length l_a of the main arc.

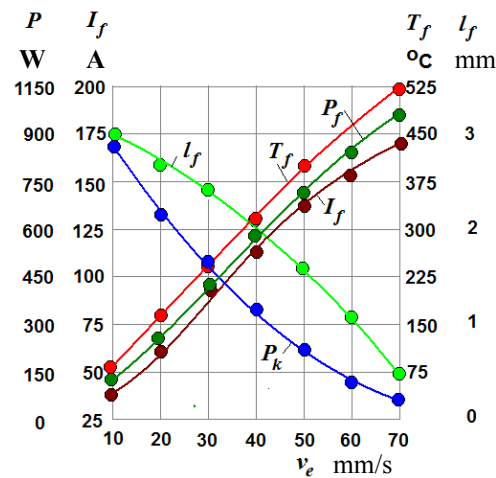


Figure 3. Dependence of the additional arc parameters on the feed rate v_f of a filler wire with a diameter of $d_e = 1.2$ mm from Inconel 625 alloy at a stick out of $l_e = 10$ mm, a supply voltage of $U_e = 32$ V, pulse ratio $t_o/\tau = 0.5$, and a main arc current of $I_e = 185$ A.

4. Discussion

Heat flows of arcs and droplets of electrode and filler metal cause melting and formation of a molten pool with stirring. The pressure of the arc and the droplet stream extrudes the melt, forming a curved surface, the shape of which provides a balance between the electrodynamic pressure of the arc plasma, the pressure of the droplet stream, the gravitational and internal pressures in the melt and the capillary pressure determined by the curvature of the surface. Therefore, the physical phenomena during the formation of the molten pool is determined by the location of the active arc spot on the molten pool (Figure 1) and the droplet streams of the electrode and filler material, which changes in accordance with the given path of the torch [4]. It is the shape of this surface at the solidification boundary that forms the surface of the deposited layer.

Technological parameters of the process of formation of the molten pool are: grades of alloys of the base metal and deposited layer; diameter and feed rate of electrode and filler wires; parameters of power supplies of electric arcs; characteristics of lateral oscillation of the welding torch.

Therefore, the results of numerical modeling of the formation of the molten pool should be drawn with regard to the heat and mass transfer of the arcs and the geometric characteristics of the surfacing (Figure 4), including the minimum Y_0 and maximum Y_m width, thickness Z_H and area S_H of the cross section of the deposited layer, as well as depth Z_L and penetration S_L area of the base material.

According to [5], during surfacing with oscillations of the heating source, heat flows are unevenly distributed alongside the deposited layer and have minimum and maximum values. Given this circumstance, the geometrical characteristics should also include the dimensions of the Y_{850} , Z_{850} , S_{850} heat-affected zones, which for a steel base material are determined by the by the ultimate arrangement of isotherms of phase transformation temperatures (850 °C) and deep tempering (500 °C).

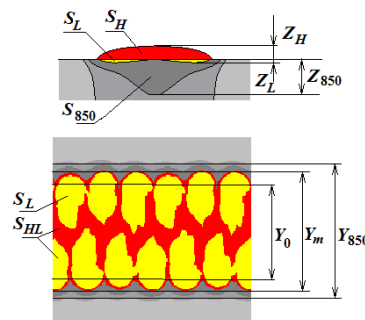


Figure 4. Geometrical characteristics of surfacing.

The presented procedures for the interaction of arcs and the values of the geometrical characteristics of surfacing allow sufficiently accurate determination of the structural transformations in the heat-affected zone and the deposited layer, its geometric shape and characteristic dimensions.

As a test example, we consider the process of surfacing with Inconel 625 wires in argon on steel 09G2S (analogy 13Mn6 – DIN, Germany) with a thickness of 20 mm. The following parameters were set: diameter of the electrode wire 1.6 mm at a stick out of 10 mm and a feed speed of 40 mm/s, diameter of a filler wire 1.2 mm at a stick out of 20 mm and a feed speed of 44 mm/s. The open circuit voltage of the main arc power source is set to 15.5 V, the arc current heating the filler wire is 100 A. The deposition speed is 5 mm/s, the amplitude of lateral oscillations is 7.5 mm, the period is 1.5 s, the delay in the extreme positions is 0.15 s. The result of solving the equations of the model is shown in Figure 5.

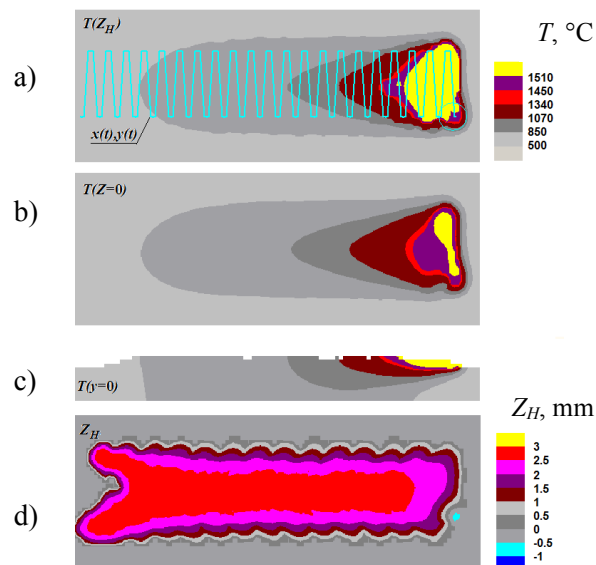


Figure 5. The result of solving the equations of the molten pool formation:

- a) temperature distribution $T(Z_H)$ and trajectory $x(t)$, $y(t)$ of the electrode center on the metal surface Z_H ; b) on the surface of the steel base material; c) along the plane of symmetry in the direction of surfacing; d) topographic image of the surface of the deposited layer.

As a result of numerical modeling, the following steady-state surfacing process parameters are obtained:

- electrode current 240 A, current on the deposited surface 140 A;
- components of the heat flow into the metal: cathode spot power 646 W, droplets of electrode wire 946 W, filler wire 636 W;
- average values of the volume of liquid metal in the molten pool: steel 14.4 mm³, Inconel 237.4 mm³;
- maximum dimensions of the deposited layer: width 18.8 mm, height 1.9 mm, penetration depth of the steel base material 0.8 mm.

5. Conclusion

The obtained results show that the main heat source is the heat of droplets of the electrode and filler material, the heat flow of which (1582 W) is significantly greater than the heat release in the cathode spot (646 W). The distribution of this power over the metal surface is determined mainly by the amplitude of lateral oscillation of the electrode (± 7.5 mm), which determines the width of the deposited layer (18 mm). With a small period of lateral oscillation (1.5 s) and a low deposition rate,

the width of the deposited layer varies slightly, since the molten pool covers almost the entire width of the deposited layer. The arc pressure on the molten pool is insignificant due to the small arc current burning between the electrode and the surface of the molten pool (140 A), which eliminates the formation of a crater in the melt, leading to a deeper penetration of the steel base material. The presented data indicate that it is possible to form a deposited layer with minimal penetration (not more than 0.8 mm) and only partial contact of the layer with the base material (37%). Most of the liquid Inconel (59%) is in contact with steel in a solid-liquid state, since the Inconel melting point (1340 °C) is lower than the solidus temperature of the steel (1450 °C). This provides a small iron content in the deposited layer, which is estimated by the ratio of the volumes of molten steel and the deposited Inconel value of less than 6%.

As part of the implementation of the Industry 4.0 concept, the creation of models and prototypes using the capabilities of wire arc additive manufacturing (WAAM – Wire Arc Additive Manufacturing) using wire for layer-by-layer deposition of material is given the most serious attention [6]. In view of this, the research results can be used in the additive hardfacing production using industrial robots.

Acknowledgement

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